A comparative study of root canal preparation with NiTi-TEE and K3 rotary Ni-Ti instruments

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Abstract

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Aim To evaluate and compare several parameters of curved root canal preparation using two different Ni-Ti systems: NiTi-TEE (Sjöding Sendoline, Kista, Sweden) and K3 (Sybron Endo, Orange County, CA, USA).

Methodology Fifty extracted mandibular molars with mesial root canal curvatures ranging from 20 to 40° were divided into two groups. In one group, 50 root canals were instrumented using NiTi-TEE files to an apical size 30; 0.04 taper (the largest available size at the time of this study). In the other group, 50 root canals were prepared with K3 instruments to an apical size 45; 02 taper. Both systems were used in a crowndown manner, with copious NaOCl (3%) irrigation and a chelating agent (Calcinase Slide, lege artis, Dettenhausen, Germany), employing torque-controlled motors. For assessment of shaping ability, pre- and postinstrumentation radiographs and cross-sectional photographs of canals were taken and changes in canal curvature and root canal diameter documented. Cleaning ability was evaluated by investigating specimens of the apical, medial and coronal third of the root canal wall under a scanning electron microscope using 5-score indices for debris and smear layer. Procedural errors (instrument separations, perforations, apical blockages, loss of working length) and working time were recorded. Nonparametric ANOVA was used to compare straightening of canal curvatures, canal cross-sections and canal wall cleanliness ($P < 0.05$), whereas working time was analysed using the parametric ANOVA ($P < 0.05$).

Results Both Ni-Ti systems maintained curvature well: the mean degree of straightening was 0.2° for NiTi-TEE and 0.4° for K3 with no statistical significance between the groups. Post-instrumentation cross-sections of the root canals revealed an acceptable contour (round or oval) in 50.6% of cases for the NiTi-TEE group and in 65.3% of cases for the K3 group. The difference was not significant. The SEM investigation of canal walls showed equally good debris removal for both systems: NiTi-TEE prepared canal walls in 74.7% of cases with scores I and II; K3 achieved these scores in 78.7% of cases. For smear layer, NiTi-TEE and K3 only received good scores (I and II) in 38.7% and 40% of canal wall specimens, respectively. For both parameters, no significant differences were found between groups. File fractures did not occur, but loss of working length was observed in one case following the preparation with NiTi-TEE and in three cases during K3 instrumentation. Mean working time was significantly shorter for NiTi-TEE (170 s) than for K3 (208 s).

Conclusions Both systems maintained original canal curvature well and were safe to use. Whilst debridement of canals was considered satisfactory, both systems failed to remove smear layer sufficiently.

Keywords: automated root canal preparation, K3, Ni-Ti instruments, NiTi-TEE.

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Introduction

Various challenges during root canal preparation, especially straightening of curved root canals, were minimized by the introduction of Nitinol into endodontics (Hülsmann *et al.* 2005). With their two to three times

higher elastic flexibility and a superior resistance to torsional fracture than conventional stainless steel files, such instruments seem predestined for use in curved root canals (Peters 2004, Hülsmann *et al.* 2005). Also, Ni-Ti instruments are manufactured with varying tapers, facilitating the achievement of a funnel shaped, continuously tapered canal preparation. However, one of the main disadvantages of Ni-Ti rotary instruments is the potential risk of fracture. Some investigations suggest that the combination of Ni-Ti rotary instrumentation and a manual creation of a glide path with stainless steel instruments can significantly reduce failure rate (Patiño *et al.* 2005). Few studies have evaluated the cleaning ability of rotary Ni-Ti files (Hülsmann *et al.* 2001, 2003, Schäfer & Lohmann 2002, Versümer *et al.* 2002, Schäfer & Schlingemann 2003, Paqué *et al.* 2005).

The aim of the present study was to evaluate several parameters of automated root canal preparation using NiTi-TEE and K3 rotary Ni-Ti instruments. The parameters analysed were: straightening of curved root canals, pre- and postoperative root canal diameter, incidence of procedural errors such as instrument fractures, perforations, loss of working length and working time. The same methodology was used as in previous studies (Hülsmann *et al.* 1999, 2001, 2003, Versümer *et al.* 2002, Paqué *et al.* 2005) to allow comparison amongst different Ni-Ti systems.

Materials and methods

Preparation of teeth

A simultaneous evaluation of preparation form (longitudinal and cross-sectional), cleaning ability, working safety and working time in extracted teeth was accomplished by utilizing a modified version of the Bramante model (Bramante *et al.* 1987, Hülsmann *et al.* 1999). A metallic muffle-block was constructed, consisting of a *U*-shaped middle section and two lateral walls that were assembled with three screws. Teeth were mounted into the mould with acrylic resin. Grooves in the walls of the muffle-block allowed removal and exact repositioning of the complete tooth-block unit or sections of the tooth. A modification of a radiographic platform (Southard *et al.* 1987, Sydney *et al.* 1991) could be adjusted to the outsides of the *U*-shaped centre of the muffle, which held the embedded tooth. This guaranteed a reproducible geometric alignment of the radiographic tube, the radiographic platform and the centre/tooth-unit and thereby a standardized exposure of all radiographs. Exact superimposition of pre-, intra- and postinstrumentation views was further assisted by two metallic reference objects embedded in the film holder of the platform. The system and the evaluation technique have been previously described in detail (Hülsmann *et al.* 1999).

Fifty extracted mandibular molars (stored in 0.1% thymol solution) with two mesial curved root canals were accessed coronally and checked for apical patency; a size 10 reamer was inserted until its tip was visible at the level of the apical foramen. A coronal reference point for each canal 19 mm from its apical foramen was created by shortening all molar crowns accordingly. The teeth were embedded in the muffle system. After insertion of a size 15 reamer, preinstrumentation radiographs were taken to measure root canal curvatures as described by Schneider (1971). The teeth were randomly divided into two groups. By exchanging a small number of teeth, a similar mean degree of curvature was achieved for both groups. The mesial canals were instrumented, mimicking clinical conditions by isolating the teeth with a rubber dam and a clamp, which reinforced mesial access of the teeth only.

Twenty-five teeth with 50 curved mesial root canals were prepared with the NiTi-TEE system, and 25 were prepared with K3 rotary instruments.

Instruments and preparation techniques

In both groups, each file was discarded after the preparation of five root canals. Canals were irrigated with 2 mL NaOCl (3%) using a syringe with a gauge irrigation tip (size 40) before each subsequent instrument was inserted. Calcinase slide, an EDTA-containing paste (lege artis, Dettenhausen, Germany), served as a chelating agent.

NiTi-TEE

The NiTi-TEE rotary system (Sjöding Sendoline) comprises seven Ni-Ti files (two K-type Coronal Shapers and five files with a modified S-profile). Common to all files is a rounded noncutting tip. The S-type flute design is characterized by two 90° cutting edges without radial lands. Flutes at base are twice the size of flutes at the tip. Following the manufacturer's instructions, the crown-down preparation was completed in four main steps:

- *Initial coronal preparation*
  Size 30; 0.12 taper (1.5 Ncm, 300 r.p.m.): was used to open the coronal region.
  Size 30; 0.08 taper (1.5 Ncm, 300 r.p.m.): was used to depth of 1/3 WL (6 mm) to 1/2 WL (9 mm), whilst avoiding gliding into the canal curvature.

- *WL preparation*
  Size 30; 0.06 taper (0.9 Ncm, 200 r.p.m.): was used a few millimetres deeper into the root canal
  Size 30; 0.04 taper (0.9 Ncm, 200 r.p.m.): was used a few millimetres deeper into the root canal
  Size 25; 0.04 taper (0.9 Ncm, 200 r.p.m.): usually reached WL (18 mm), if not, continued with:
  Size 20; 0.04 taper (0.9 Ncm, 200 r.p.m.): and, if necessary: size 20; 0.02 taper (0.9 Ncm, 200 r.p.m.).
- *Apical preparation*
  Size 20; 0.04 taper (0.6 Ncm, 150 r.p.m.): used to full WL
  Size 25; 0.04 taper (0.6 Ncm, 150 r.p.m.): used to full WL
  Size 30; 0.04 taper (0.6 Ncm, 150 r.p.m.): used to full WL.
- *Final preparation*
  Size 30; 0.12 taper (1.5 Ncm, 300 r.p.m.) and size 30; 0.08 taper (1.5 Ncm, 300 r.p.m.): used to maximum depth of two-thirds of WL in order to smooth the canal walls and create a continuous funnel shape.

Instrument sizes 35, 40 and 45 were not available at the time of this investigation. Total number of instruments used was 8–12.

The system was used in conjunction with the Endo IT Control motor (VDW-Antaeos, Munich, Germany) with torque limitations and rotational speed as described above and as recommended by the manufacturer.

K3

The K3 system was used with its compatible K3etcm torque-controlled motor (Kerr, Karlsruhe, Germany) and an 18 : 1 reduction handpiece (W&H, Buermoos, Austria). The torque setting was three (according to manufacturer an equivalent of 1.2 Ncm) and the rotational speed 300 r.p.m. Instruments were advanced apically in a gentle pecking motion until the first sign of resistance was felt. The following 10 instruments were chosen to create a crown-down sequence of 12 steps:

- *Coronal Preparation*
  Size 25; 0.10 taper: orifice shaper
  Size 25; 0.08 taper: orifice shaper 1/3–2/3 of WL.
- *Crowndown to WL* (proceeding in 1 mm increments)
  Size 30; 0.06 taper: 2/3 to 14 mm
  Size 30; 0.04 taper: 2/3 to 15 mm
  Size 25; 0.06 taper: 2/3 to 16 mm
  Size 25; 0.04 taper: 2/3 to 17 mm
  Size 20; 0.04 taper: full WL.
- *Apical preparation*
  Sizes 25–45; 0.04 taper: full WL.

The total number of instruments used was 12.

Assessment of preparation

After preinstrumentation radiographs of the two mesial canals were taken, the preparation of the mesio-buccal root canals followed in the yet unsectioned tooth. Information was gathered on maintenance of canal curvature, working safety (loss of WL, apical blockage, instrument separation and lateral perforation) and working time.

For the purpose of evaluating a gradual change in the degree of curvature during rotary instrumentation, radiographs were taken at different stages of preparation: for the NiTi-TEE group after completion with files size 25; 0.04 taper and size 30; 0.04 taper and for the K3 group after finishing with files size 25; 0.04 taper, size 30; 0.04 taper and size 45; 0.02 taper. Before attaching the radiographic platform and exposing the film, a corresponding file was inserted. In addition, a master point film was taken of each canal to evaluate the conicity of the final preparation form. With the aid of the metallic reference points and traced root contours, subsequent radiographs could be superimposed under an X-ray viewer with a 10× magnification. The position of the subsequent, larger file was traced and compared with the previous file's position. The degree of straightening was evaluated by measuring the angle between the two instrument tips. With the mesio-buccal canals being prepared and evaluated, the tooth/resin-unit was sectioned horizontally at 3, 6 and 9 mm from the apex, and the preoperative root canal diameters were photographed through a stereomicroscope under the standardized conditions. After exactly repositioning the cross-sections into the muffle, the mesio-lingual canals were instrumented as described above. Again, procedural problems were recorded and straightening of canal curvatures was measured. Upon completion of instrumentation, the mesio-lingual cross-sections were photographed a second time. According to Loushine *et al.* (1989), the cross-sections were classified as round, oval or irregular using reference photographs. Only irregular cross-sections were considered as unacceptable preparation results because an oval cross-section may occur as a result of the cutting

angle during the sectioning procedure, which may or may not be exactly perpendicular to the long axis of the root canal. The divergence of original and instrumented root canal diameters was evaluated by superimposing pre- and postoperative canal contours.

For the SEM evaluation, specimens were exclusively extracted from the mesio-buccal root canal because in the sectioned mesio-lingual canals sufficient chemical cleaning could have been compromised because of irregular hydrodynamics. The apical, middle and coronal segments of the mesio-buccal roots were freed of the surrounding resin, split vertically and their buccal halves prepared for the SEM investigation.

Two separate investigations, each based on a 5-score index, were conducted for debris and smear layer, using the same set of reference photographs as in previous evaluations (Hülsmann *et al.* 1999, 2001, 2003, Versümer *et al.* 2002, Paqué *et al.* 2005).

Debris was defined as dentine chips, pulp remnants and particles loosely attached to the root canal wall.

- Score I: clean root canal wall, only few small debris particles.
- Score II: few small agglomerations of debris.
- Score III: many agglomerations of debris covering less than 50% of the root canal wall.
- Score IV: more than 50% of the root canal wall covered by debris.
- Score V: complete or nearly complete root canal wall covered by debris.

Scoring of debris was performed at 200× magnification.

Smear layer was defined as proposed by the American Association of Endodontists' (1994) glossary 'Contemporary Terminology for Endodontics' as: a surface film of debris retained on dentine or other surfaces after instrumentation with either rotary instruments or endodontic files, and consisting of dentine particles, remnants of vital and necrotic pulp tissue, bacterial components and retained irrigant.

- Score I: no smear layer, dentinal tubules open.
- Score II: small amount of smear layer, some dentinal tubules open.
- Score III: homogeneous smear layer covering the root canal wall, only few dentinal tubules open.
- Score IV: complete root canal wall covered by a homogeneous smear layer, no open dentinal tubules.
- Score V: heavy, inhomogeneous smear layer covering the complete root canal wall.

Smear layer was rated under a 1000× magnification.

At a 10× magnification, the SEM operator directed the central beam of SEM to the centre of the object, then increased the magnification to 200× and 1000×, respectively. The canal wall region appearing on the screen was scored. This procedure was performed by an independent operator, who was neither familiar with the instrumentation of the canals nor the coding of the specimens. This operator had been trained in the scoring procedure intensively, yielding a sufficient intraobserver reproducibility (Hülsmann *et al.* 1997).

The incidence of procedural errors during instrumentation was recorded for the mesio-buccal (unsectioned) and the mesio-lingual (sectioned) canals. Apical patency was controlled between each file exchange with a size 10 reamer extending 1 mm beyond WL.

Statistical analysis

Nonparametric ANOVA (Brunner *et al.* 2002) was used to compare straightening of canal curvatures, canal cross-sections and canal wall cleanliness ($P < 0.05$), whereas working time was analysed with parametric ANOVA ($P < 0.05$).

Results

Distribution of preoperative root canal curvatures

The mean preoperative degree of curvature was 27.8° (minimum: 20°, maximum: 39°) for the NiTi-TEE group and 27.7° (minimum: 20°, maximum: 38°) for the K3 group.

Straightening

The mean degree of straightening after preparation to size 30; 0.04 taper in the NiTi-TEE group was 0.2°. The K3 group was instrumented up to a size 45; 0.02 taper with a mean degree of straightening of 0.4° (Table 1).

Table 1 Results for straightening of root canal curvature (in °)

	NiTi-TEE		K3	
	Unsectioned roots	Sectioned roots	Unsectioned roots	Sectioned roots
n	25	25	25	25
Mean preoperative curvature	29.1	26.4	29.0	26.3
Minimum	0	0	0	0
Maximum	2	4	1.5	8
Median	0	0	0	0
Mean degree of straightening	0.18	0.28	0.16	0.72

Table 2 Results for contours of postoperative cross-sections

Section	NiTi-TEE ($n = 75$)	Acceptable	K3	Acceptable ($n = 75$)
Coronal				
Round	5	18	7	18
Oval	13		11	
Irregular	7		7	
Middle				
Round	4	11	3	16
Oval	7		13	
Irregular	14		9	
Apical				
Round	2	9	5	15
Oval	7		10	
Irregular	16		10	

The difference was not statistically significant (nonparametric ANOVA, comparison of both systems: $P = 0.753$; comparison of unsectioned and sectioned canals: $P = 0.519$).

Cross-sections

The distribution of round, oval and irregular cross-sectional canal contours is summarized in Table 2. The K3 system yielded an acceptable round or oval diameter form in the majority of cases (65.3%) and showed no statistically significant difference in preparation of coronal, medial and apical canal segments (ANOVA: $P = 0.640$). The NiTi-TEE system produced a lower number of acceptable forms (50.6%), though this difference was not significant ($P = 0.093$). However, a significant difference ($P = 0.013$) was found between NiTi-TEE's instrumentation of the three root canal thirds. NiTi-TEE files created significantly more acceptable shapes in the coronal third than in the middle ($P = 0.010$) and apical ($P = 0.010$) third. Contours of apical and middle canal cross-sections did not differ significantly ($P = 0.532$).

Superimposition of pre- and postinstrumentation cross-sectional photographs revealed uninstrumented canal areas in both groups. Ideally, the contact area between superimposed original and prepared canal diameter should be 0% in every third of the canal, meaning that no uninstrumented canal wall is present. This specific case was only achieved in two canals of the NiTi-TEE group and six canals of the K3 group. Generally, 33 (44%) of the 75 cross-sections in the NiTi-TEE group had 0% contact compared with 45 (60%) in the K3 group (Table 3). Nonparametric ANOVA showed the difference between the two groups to be not significant ($P = 0.091$). The comparison of the apical, medial and coronal thirds revealed no significant difference either ($P = 0.195$).

Root canal cleanliness

Table 4 presents the results of the SEM investigation for debris and smear layer in each third of the root canal. Debris: both systems achieved a debridement equivalent to score I in 33 cases. Combined with 23 (NiTi-TEE) and 26 (K3) score-II-ratings, they represented the majority of specimens (74.7% in the NiTi-TEE group; 78.7% in the K3 group). However, only two canals of each group were entirely cleaned of debris (coronal, medial and apical third received score I). In seven cases for NiTi-TEE and nine for K3, the evaluation of the

Table 4 Results of the evaluation of remaining debris and smear layer

	NiTi-TEE ($n = 75$)				K3 ($n = 75$)			
Score	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
Debris								
1	12	15	6	33	16	11	6	33
2	9	7	7	23	8	12	6	26
3	3	2	7	12	1	2	5	8
4	0	1	3	4	0	0	5	5
5	1	0	2	3	0	0	3	3
Smear layer								
1	9	8	1	18	16	3	0	19
2	5	3	3	11	3	6	2	11
3	7	6	5	18	4	4	7	15
4	1	5	7	13	1	6	5	12
5	3	3	9	15	1	6	11	18

Table 3 Contact between pre- and postoperative root canal cross-sections

Contact between pre- and postoperative cross-sections (%)	NiTi-TEE ($n = 75$)				K3 ($n = 75$)			
	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
>75	0	0	0	0	0	0	0	0
>50	0	0	0	0	1	0	1	2
>25	4	4	5	13	1	1	5	7
0–25	9	9	11	29	10	6	5	21
0	12	12	9	33	13	18	14	45

entire canal resulted in a mixture of score I- and score II-ratings. With 9.3% (NiTi-TEE) and 10.7% (K3), the worst scores (IV and V) accounted primarily for the apical specimens of the canal. The cleaning ability of the two systems did not differ significantly ($P = 0.55$). The degree of cleanliness for the entire canal showed great differences between the coronal and medial segment compared with the apical segment, where significantly more residual debris was found ($P < 0.001$). Smear layer: Considering scores I and II as acceptable results, 38.7% and 40% of the specimens have been sufficiently cleaned of smear layer with the NiTi-TEE and K3 system, respectively (Table 4). There was a general tendency of worse results for the apical third. The nonparametric ANOVA showed a significant interaction ($P = 0.022$) between the file systems and the canal locations.

Procedural errors

Each file was used in five canals and no fracture occurred in either group. In the K3 group, three losses of working length were recorded, whilst one was observed in the NiTi-TEE group. The most severe loss of working length (K3: 2.0 mm) did not have clinical relevance because it was rather a technical error because of the sectioning of the canal. The remaining losses of working length developed in unsectioned root canals and measured 0.3 mm for both systems.

Working time

Mean working time for the preparation of unsectioned root canals, excluding time for irrigation and file exchange, was significantly shorter with the NiTi-TEE system (170 s) than with the K3 system (208 s) (Parametric ANOVA: $P = 0.036$). The NiTi-TEE system was used with mainly six files in a sequence of 10 steps (at few times 12 steps, if the file size 20; 0.02 taper was needed to reach WL).

The sequence for the K3 system comprised 10 files, which were employed in 12 steps.

Discussion

Rotary Ni-Ti instruments have been investigated in numerous studies (for reviews see: Peters 2004, Hülsmann *et al.* 2005). Nevertheless, underlying experimental designs vary greatly, often prohibiting comparison, even if the same devices and techniques were used. As part of a series of studies, this investigation was performed according to the Göttingen experimental design, allowing the collection of data on the shaping and cleaning ability as well as on the safety issues and working time for two recently introduced Ni-Ti systems and, even more important, subsequently a comparison of the results with previous investigations of this series (Hülsmann *et al.* 2001, 2003, Versümer *et al.* 2002, Paqué *et al.* 2005). Given the complex root anatomy and the variability in dentine hardness, the use of extracted teeth compromises standardization to a certain extent, but more importantly enables SEM investigation of canal cleanliness and provides conditions close to the clinical situation. Whilst simulated canals in resin blocks are a method to standardize conditions with regard to the degree and radius of curvature (Dummer *et al.* 1991) and the abrasiveness (Tepel *et al.* 1993), their use does not reflect the action of instruments in root canals of real teeth (Schäfer & Lohmann 2002). Kum *et al.* (2000) pointed out that the resin material is not ideal for a study of rotary instruments because it does not respond in the same way as dentine, and if instruments are used in a grinding action, the generated heat may sometimes soften the resin material so that cutting blades may bind and consequently break (Thompson & Dummer 1997c).

It should be noted that the final apical preparation sizes in the present study were not identical for both groups as it was decided to follow rather the manufacturers' recommendations for the use of the respective systems than to aim at identical geometrical outcomes of preparation. This of course may have resulted in differences in straightening, cleanliness and working time between the two systems investigated.

Straightening of curved canals

The results of the present study reconfirm that Ni-Ti rotary files respect canal curvature very well (Thompson & Dummer 1997a,b, 1997c,d, 1998a,b, Bryant *et al.* 1998a,b, Hülsmann *et al.* 2001, 2003, Versümer *et al.* 2002, Schäfer & Schlingemann 2003, Paqué *et al.* 2005). The instruments of both groups were designed with a safe, noncutting tip, which has proven to be superior to more aggressive designs in keeping the file centered and thus preventing canal transportation (Thompson & Dummer 1998a,b, Hülsmann *et al.* 2001). Whilst the K3 file was introduced as a file of the third generation with an asymmetric cross section, radial land reliefs and a slightly positive rake angle, the

NiTi-TEE instrument features a modified S-file design, with two 90° cutting edges, but no radial lands. No significant difference in the degree of straightening was found, which could indicate that the tip design might be more influential on the shaping outcome than the shaft design.

In simulated canals as well as in extracted teeth with canal curvature ranging from 28 to 35° and 25 to 35°, respectively, it was found that rotary preparation with K3 instruments resulted in significantly less straightening than with K-Flexofiles (Schäfer & Florek 2003). In part II of the study using extracted teeth, Schäfer & Schlingemann (2003) determined initial and post-instrumentation degree and radius of curvature with a computerized digital image-processing system. A mean degree of straightening of 1.36° was measured after K3 instrumentation (compared with 6.91° for K-Flexofiles). In the present study, canals of the K3 group experienced a mean degree of straightening of 0.4°. One main reason for this difference might be the different techniques of measurement of curvatures. In comparison with previous investigations under identical experimental conditions, both systems maintained the curvature comparable with the FlexMaster system and HERO 642 and slightly better than the Lightspeed and ProFile systems, although this has not been evaluated statistically. Good shaping ability for K3 instruments previously has been reported by further investigations in simulated root canals (Ayar & Love 2004, Yoshimine *et al.* 2005) and extracted teeth (Bergmans *et al.* 2003). As of now, no investigation on the shaping ability of the NiTi-TEE rotary system has been published.

Cross-sections

The assessment of pre- and postoperative canal cross-sections can provide various information on a file's shaping ability. This study evaluated preparation form qualitatively and amount of uninstrumented canal areas quantitatively at three levels of horizontally segmented roots. By employing an XMCT-scanner, Bergmans *et al.* (2001) could nondestructively obtain perpendicular slices at five horizontal levels and analyse the mesial canals of 10 three dimensionally reconstructed extracted mandibular molars before and after preparation with ProTaper versus K3 instruments. These five virtual cross-sections allowed calculation of linear dentine removal (transportation) and centring ability and revealed a different pattern for transportation for both systems. Constantly tapered K3 instrumentation (including 0.08 and 0.10 tapers) showed more dentine removal towards the outer aspect of the curve at the middle-apical level and caused a centre displacement towards the outer side of the curvature more apically, whilst progressively tapered ProTaper files tended to transport towards the furcation coronally. Both systems showed overall capability of preparing curved canals with optimum morphological characteristics.

The current investigation presented, particularly for the apical and medial segment, less acceptable cross-sectional canal contours after preparation than were observed in previous evaluations. Lightspeed, ProFile 0.04, (Versümer *et al.* 2002), HERO 642 and FlexMaster (Hülsmann *et al.* 2001, 2003) systems created approximate round or oval (acceptable) forms in 71% to 87% of cases, whilst K3 achieved only 65.3% and NiTi-TEE only 50.6%. A previous investigation of Quantec SC in this series yielded acceptable shapes in only 53% of cases (Hülsmann *et al.* 2001). According to the manufacturers both, K3 and Quantec SC, feature a slightly positive rake angle and three radial lands, which are all (Quantec SC) or only two (K3) relieved. HERO 642 also possesses a slightly positive rake angle but no radial lands. The results obtained for the NiTi-TEE system emphasize a potential relation between file design and quality of post-instrumentation canal diameter. The coronal third showed significantly more acceptable results than the remaining two levels, which could be attributed to the use of two K-type orifice shapers coronally. The medial and apical third were prepared by instruments featuring a modified S-file design and two 90° cutting edges.

When contact area was assessed between superimposed pre- and postoperative canal cross-sections, only six canals in the K3 and two canals in the NiTi-TEE group showed no uninstrumented canal area in all three sections. Overall, the K3 system yielded more (60%) superimposed cross-sections with a 0% contact area than the NiTi-TEE group (44%). The slight superiority of K3 instrumentation, although not being significant, can probably be attributed to its larger apical preparation. The distribution of results is in accordance with the majority of previous studies in this series, where between 39–60% of cross-sections revealed unprepared canal areas.

Cleaning ability

The controversy about removal or preservation of the smear layer is ongoing. Whether or not smear layer

removal is preferable, there is no doubt that debris removal is mandatory in order to eliminate most of the microorganisms from the root canal system. Complete to nearly complete debris removal in up to 78.7% (K3) and 74.7% (NiTi-TEE) of the specimens showed consistent results with previously investigated systems in this series. Although larger preparation sizes with K3 should be expected to allow deeper penetration of the irrigation needle and increased cleanliness, the difference between both systems was not significant. Residual debris was significantly more frequent in the apical specimens, which in agreement with previous results as well as with a recently published study by Schäfer & Schlingemann (2003), which was based on the same SEM 5-score evaluation index, although no EDTA was used and magnification settings differed. They compared the cleaning efficacy of the K3 system versus the K-Flexofile and observed, on average, more effective cleaning in the coronal and middle thirds of canals. The K-Flexofiles were significantly superior in debris removal, but no significant differences were found for residual smear layer. A final irrigation with a liquid EDTA solution probably would increase the degree of cleanliness (Calt & Serper 2000).

Working safety

In contrast to previous studies, the number of root canals prepared with each file has been reduced from 10 to five canals in the present study. Although this change might impair comparability, it meets manufacturers' recommendations better, who mostly advocate to discard instruments after the preparation of one severely curved canal. The results of no file fracture in either system may reflect this change. The operator was familiar with both systems in preliminary trials, but had no prior experience with Ni-Ti rotary instrumentation. Schäfer & Schlingemann (2003) recorded five fractures of K3 files when preparing mandibular and maxillary molars with curvatures ranging from 25 to 35°, although instruments were used to enlarge one canal only. The use of a chelating agent and the prior opening of the orifices might have reduced some of the stress exerted on the files and could explain the absence of fractures in this study. Patiño *et al.* (2005) in an investigation including the K3 system concluded that a glide path, prepared with stainless steel files (size 10–20), can reduce the separation rate of Ni-Ti rotary instruments significantly.

Another recent study by Ankrum *et al.* (2004) investigated breakage and distortion of ProFile, ProTaper and K3 instruments in severely (40–75°) curved canals and found no significant difference for breakage. No publications were found on the safety of NiTi-TEE. In the present study, besides a loss of working length of 0.3 mm in two cases for K3 (not counting one loss because of a technical error in a sectioned canal) and one for NiTi-TEE, no procedural errors were documented.

Working time

Time for preparation of one root canal was significantly longer for K3 than for NiTi-TEE. This could be in part attributed to a higher number of instruments (10) in the K3 sequence and a larger final apical preparation. The instruments size 25; 0.04 taper and size 30; 0.04 taper were each used twice in the K3 sequence, which resulted in 12 steps, if no recapitulations were necessary. The NiTi-TEE sequence incorporated seven different files, although the file size 20; 0.02 taper was actually only needed in three cases. In the majority of cases, six files were used in 10 steps to achieve an apical size of 30; 0.04 taper. In previous investigations based on the same design, canals were mostly prepared up to size 45 (if sizes were available), so that most sequences included 10 steps (apart from Lightspeed preparation). Mean working times (without irrigation) varied from 71 to 161 s. In the present study, the mean time for NiTi-TEE was 170 s and for K3 208 s. These longer preparation times could be attributed to the operator's influence as well as to the cutting efficacy of the instruments. Whilst Schäfer & Florek (2003) could show a significant advantage in working time of K3 versus hand K-Flexofiles in simulated canals, K3 instrumentation time in extracted teeth was still less, but without a significant difference. Including total active instrumentation, instrument changes within the sequence and irrigation (with 5 mL NaOCl), Schäfer & Schlingemann (2003) recorded a mean working time of 7.21 min (441 s) for K3 (eight steps) in extracted mandibular molars. In the present study, the mean working time for K3 (12 steps) including irrigation time (2 mL) was 420.9 s. González-Rodríguez & Ferrer-Luque (2004) measured dentine removal in mandibular-curved canals for ProFile, HERO 642 and K3 instruments and found that HERO 642 eliminated significantly more dentine and showed a superior cutting efficacy than the other systems. When Hülsmann *et al.* (2003) compared the FlexMaster (10 steps) and the HERO 642 (nine steps) system, they found working times of 71 and 66 s, respectively, which

could be interpreted as a better cutting efficacy of these files. Chow *et al.* (2005) examined the cross-sections of K3 and ProFile instruments and determined that both files show negative rake angles, even if the K3 file might appear to have a positive rake angle when evaluated visually. This opposes manufacturer's description, but could explain why studies reported lower cutting efficiency. As no studies have been published on NiTi-TEE, the system cannot be compared.

Conclusions

The results of the present study confirm the results of previous studies on rotary Ni-Ti systems concerning good maintenance of root canal curvature and centring ability. Both systems were not able to remove debris and smear layer completely. Both systems were safe to use.

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